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ENERGY EFFECTIVITY OF AIR SOURCE HEAT PUMP

The paper presents the results of simulation of heat pump air-to-air. Numerical design of the main heat exchangers initially performed for a nominal regime with heating capacity 10.5 kW: evaporator and condenser with heat exchange surface of the minimum weight of the bimetallic finned tubes with fins optimal parameters and restriction to the pressure loss.

Obtained the distribution pressure losses in the heat pump circuit by the working substance of the main and auxiliary heat-exchange apparatus.

The greatest losses are observed in the evaporator and indicates the maximum permissible.

In the following analysis was held of the heat pump in the off-design regimes when the air temperature changes, which was a source of low-grade heat.

Based on this analysis reached the following conclusions:

– the main influence on the energy perfection of the heat pump is an irreversible losses and outside temperature. Losses in the evaporator are crucial. At low temperatures requires a reserve heat source;

– selection of the heat pump must be carried out on the basis of complex comparative analysis and optimal design for each case their use. This approach allows to select a heat pump with the best energy characteristics;

– method of analysis of the conjugate heat pump air-to-air can be used with pre-adaptation for other types of heat pumps.

Key words: heat pump, numerical simulation, pressure losses, heating capacity, coefficient of performance, energy efficiency.

Introduction. In many countries heat pumps are widely used for the purpose of energy-saving, to replace scarce fuel or traditional heat sources. The development of this area is foreseen by policy documents of the Republic of Belarus [1, 2]. The analysis and study of the possibility of industrial and municipal use of heat pumps is conducted [3–5]. Conditioners for life and office are mainly used as heat pumps in heating mode. The heat pumps have no proper application in the country. One reason for this is a lack of clear criteria to determine the area of their effective application.

In works [6–10] heat pumps are regarded in functional purpose of their application, region and country. From the analysis of these studies it follows that the largest number of heat pumps are used in developed countries for heating, hot water and centralized heating. For example, climatic conditions in winter period in majority of European countries are milder than in Belarus. Therefore, in heat pumps for individual use as a low grade heat source air is used [9, 10]. At the same time the heat of soil, groundwater, reservoirs and waste heat are used. It is difficult to do unequivocal conclusions about the efficiency of consumption of heat-pumps because of differences in the economy and priorities in energy policies of individual countries. The vapor compression pumps are used as a main type of heat pumps. This type is regarded below as the most promising one of the heat pumps.

In the methodical aspect the definition of energy efficiency of heat pumps is reflected. In this case methods of computational analysis are used [11–14]. In these techniques, the effect of irreversible losses is considered only in the compressor and a temperature control valve. Although in [14] the pressure losses in the heat exchangers from the refrigerant are a simply accounted, but their influence and role in the efficiency of the heat pump are not studied. At the same time it is known from experiments [15, 16] that the irreversible losses in the heat exchangers also lead to a decrease in the efficiency of the refrigerating machine, and accordingly, the heat pump.

On the energy efficiency of heat pumps both internal and external factors affect. Internal factors determine the power excellence of heat transformer and depend on the equipment and working medium. External factors include the state of the environment. They are interlinked and require a comprehensive review.

In this paper, the energetic analysis on the example of vapor compressional heat pumps “air-to-air” with a power driver is carried out. These heat pumps can operate in the mode of heating the room air, and when necessary in the reverse mode of cooling. This approach in contrast to the known methods actually takes into account irreversible losses not only in the compressor and the throttling device, but in the heat exchange apparatuses. It allows to do a comprehensive analysis of the impact of internal and external factors on energy efficiency of heat pumps.

Main part. The analysis of the energy efficiency of the tested vapor compressional heat pump is based on a modified previously developed dual method of calculation, when the parameters of thermodynamic cycle are examined together with the characteristics of heat exchangers. This method is implemented as a package of applied programs and is described in [18–20]. Note its possibilities that for the transformers (chillers and heat pumps) include:

– calculation of the specific parameters based on the reversible compression of the working medium;

– calculation of thermal parameters in view of the irreversible compression in a real compressor;

– forecasting of work at changing climatic and technological exploitation conditions taking into account the irreversible losses in heat exchangers;

– integrated calculation engineering to optimize operating and design parameters of heat exchangers;

– individual calculation of heat exchangers.

For the analysis the heat pump “air-to-air” is taken, which includes a compressor, a temperature control valve, an evaporator, a condenser and a regenerator (Fig. 1).

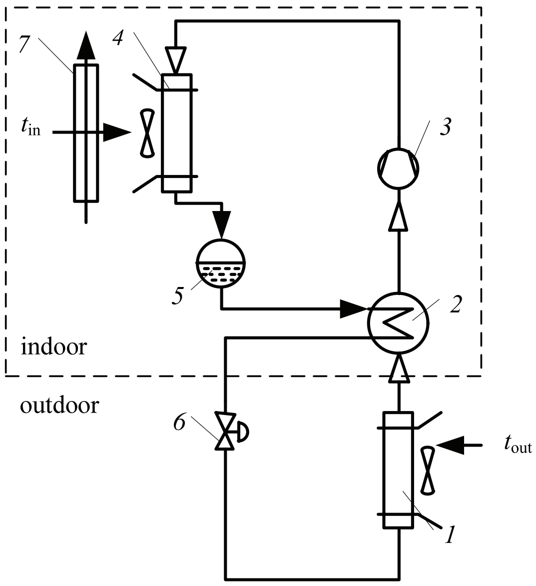

Fig. 1. Scheme of principle of the heat pump:
1 – evaporator; *2* – regenerator; *3* – compressor; *4* – condenser; *5* – receiver; *6* – temperature control valve; *7* – recovery heat exchanger

For the energy analysis the most important characteristics of heat pumps, working in a reverse mode, are heating capacity Q, cooling capacity Q_0, coefficient of performance φ and electric refrigerating factor ε. These parameters are defined considering the irreversible losses in all units: compressor, evaporator, condenser, regenerator and temperature control valve.

Coefficient of performance and refrigerating coefficient are determined by the relations:

$$\varphi = \frac{Q}{N_e}, \tag{1}$$

$$\varepsilon = \frac{Q_o}{N_e}, \tag{2}$$

$$N_e = N_c + N_v + N_{con}, \tag{3}$$

where N_e, N_c, N_v, N_{con} – the total power consumption and power consumed to drive the compressor, vaporization fans and condenser.

The working medium used in the heat pump was refrigerant R22. Heat pump is equipped with a compressor 1P10 [20], the characteristics of which for standard conditions are given in the Table.

Initially for nominal mode of heating capacity of 10.5 kW was carried out numerical design of basic heat exchangers: the evaporator and condenser with heat exchange surface of the minimum weight of the bimetallic finned tubes with optimal finning parameters under restrictions on the pressure losses. As estimated was accepted average temperature of air –10°C in the coldest month in Minsk [21]. At the condenser inlet air temperature is kept constant +15°C due to recycling or heating in recovery heat exchanger of supply and exhaust ventilation system. In the first approximation, we assumed that the temperature of the refrigerant in the evaporator is t_{ev} = –20°C, and in the condenser – t_c = –25°C under restrictions on the pressure losses in the apparatuses $\Delta p_R \le 0.04$ MPa. From the air it was assumed that the pressure loss should not exceed 100 Pa. These loss values meet the requirements foreseen to the heat pumps.

As the heat exchange surface of the evaporator and the condenser were used bimetallic finned tubes with spiral aluminum fins and the carrier steel pipe of 12×1 mm. As a result of the optimizing calculation based on the noted restrictions it was found that the mass of the evaporator with a front section F_{ev} = 0.5 m^2 is M_{ev} = 65 kg. The optimum height, width and a step of fins are equal to h_{ev} = 8.0 mm, δ_{ev} = 0.5 mm and s_{ev} = 6.3 mm at velocity of air w_{ev} = 4.2 m/s. For the condenser values of parameters were as follows: F_c = 0.58 m^2, M_c = 47 kg, h_c = 7.0 mm, δ_c = 0.3 mm, s_c = 3.4 mm and w_c = 5.1 m/s. The best step of fins in the evaporator in comparison to the step in the condenser is of greater importance because of a possible formation of hoar-frost in a cold period of the year.

The regenerator is a coil heat exchanger with a displacer, in which liquid refrigerant moves in a helical coil, and steam – in an annular gap between the housing and the displacer, winding around a coil. Computational experiments resulted in the structure of pressure losses and their share distribution on the nominal mode in the heat exchangers of the contour of the heat pump as shown in Fig. 2 and 3.

Characteristics of compressor 1P10

Parameter	Value
Refrigerant	R22
Cooling capacity, kW	12,5
Power consumption, kW	3.9
Cooling coefficient	3.21
Performed piston volume, m^3/h	32.8
Boiling point, °C	–15
Condensation temperature, °C	+30
Suction Temperature, °C	+20
Temperature upstream of the restriction, °C	+30

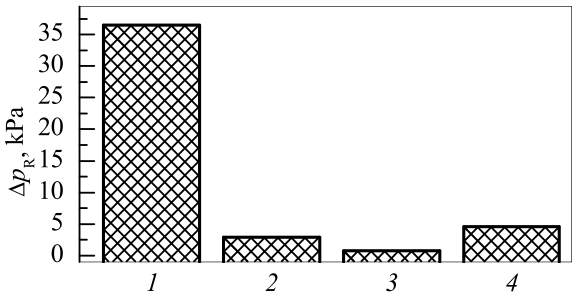

Fig. 2. The structure of the pressure losses in the heat exchangers: *1* – evaporator; *2* – condenser; *3* – regenerator (steam side); *4* – regenerator (liquid side).

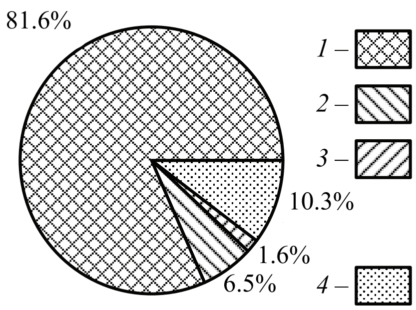

Fig. 3. Share distribution of pressure losses through the heat exchangers in the heat pump contour: *1* – evaporator; *2* – condenser; *3* – regenerator (steam side); *4* – regenerator (liquid side)

It can be seen that for a given heat pump the greatest losses of pressure occur in the evaporator. This is due to the organization of a flux in the apparatus that must have a minimum weight with restrictions on the pressure losses of fluid [17]. The optimum weight and size characteristics of the evaporator are achieved on the boundary of permissible values $\Delta p_R \approx \Delta p_{R\max}$ from the refrigerant, and in other apparatuses when $\Delta p_R < \Delta p_{R\max}$.

The influence of pressure losses on the mode parameters of the heat machine is shown in Fig. 4. It is seen that in the ideal case, when $\Delta p_R = 0$, power characteristics are improved and the absolute values of heating capacity, cooling capacity, coefficient of performance and an electric refrigerating coefficient become higher, respectively, of 7.0; 7.7; 2.4 and 2.4%. Irreversible losses have a negative influence on the operating parameters and must be taken into account in the case of design or the choice of the standard heat exchangers.

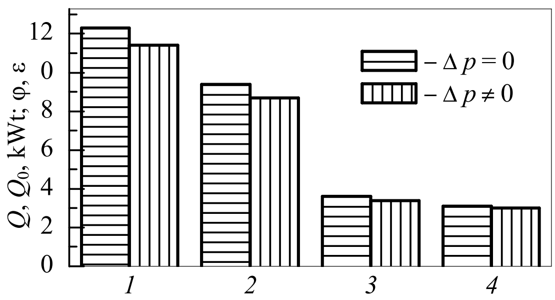

Fig. 4. Influence of pressure losses on the mode parameters of the heat pump: *1* – heating capacity; *2* – cooling capacity; *3* – recovery coefficient; *4* – refrigeration coefficient

It should be noted that the characteristics of the heat pump "air-to-air" are significantly affected by the season-climatic conditions. Dynamics of changes of major operational parameters from the air temperature is shown in Fig. 5 and 6.

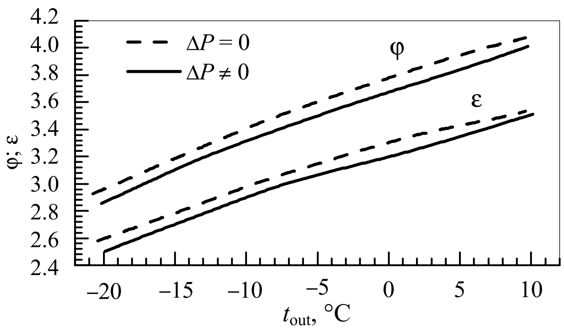

Fig. 5. Change of heating capacity Q and cooling capacity Q_0 depending on the outdoor air temperature

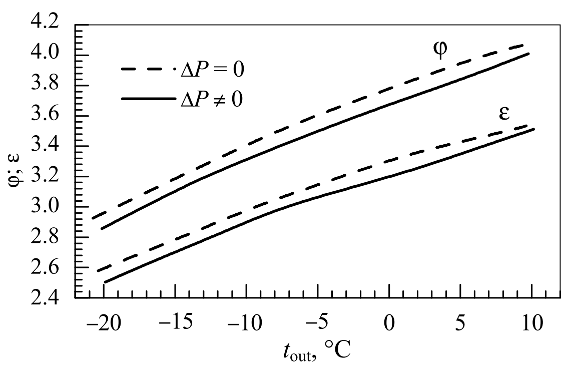

Fig. 6. Change of coefficient of performance φ and electric refrigeration coefficient ε

It is seen that at the operation of the heat pump in autumn and spring, its characteristics vary significantly. Heating capacity with an increase in air temperature from –20 to +10°C increases more than 2 times. A recovery coefficient increases accordingly. This is due to a decrease of compression ratio in the compressor. However, for the consumer of heat it would be preferable to reverse the trend. Correlation parameters can be partially improved by using adjustable fans in the evaporator and condenser, and by using combined schemes of heat pumps: two-stage or cascade [11]. Excess of heat can also be recovered after additional disposal of a water heater or a battery.

In the real heat pump irreversible pressure losses in heat exchangers reduce its energy efficiency of 5–8% in the case of an optimal selection of equipment and to a greater extent if the optimization is not performed. With the increase of air temperature when heating capacity increases, and accordingly, the refrigerant consumption the pressure losses increase (Fig. 7). To some extent it serves as a self-regulator to reduce heating capacity at a few percent in the warm months.

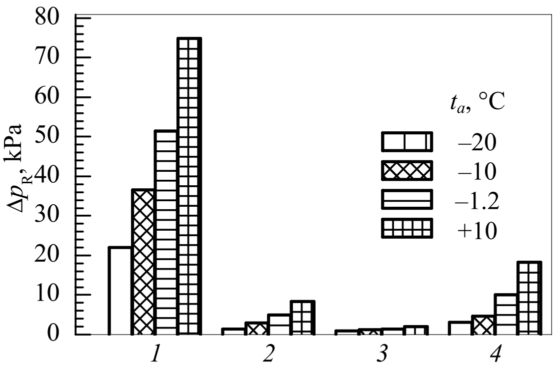

Fig. 7. Change of the pressure losses in the heat exchangers depending on the outside air temperature: *1* – evaporator; *2* – condenser; *3* – regenerator (steam side); *4* – regenerator (liquid side)

From the analysis it is clear that energy efficiency of heat pumps largely depends on the complete equipment. And one of the ways of its increase is the use of more sophisticated compressors and the decrease of irreversible losses in heat exchangers by means of constructive and circuit improvements. However, even the achievement of high coefficient of performance does not allow to make a conclusion about a desirability of the use of heat pumps to replace traditional sources. The high energy efficiency of the heat machine is a necessary but not sufficient condition. The ultimate conclusion requires an integrated technical and economic analysis, which is the subject of a separate study.

Conclusion. The results of the numerical experiment made on the base of the modified method of calculation of the heat pump "air-to-air" with an electric driver in relation to climatic conditions in Minsk are presented. Basing on the given analysis we can make the following conclusions.

The efficiency of the heat pump depends on the internal (perfect energy contour) and external (conditions of performance) factors.

The change of the temperature of a low-potential heat source (outside air) during the heating season exerts a significant influence on the characteristics of the heat pump when its heating capacity changes about twice inversely proportional to the needs of the heat. The schedule of the use of heat can be improved by using adjustable fans in the evaporator and condenser, storage devices.

The choice of heat pumps for each case of use must be conducted on the base of a comprehensive comparative analysis and optimal design. This approach will allow you to take the best correlation between the energetic and economic indicators.

The method of a conjugate analysis of the heat pump "air-to-air" can be used with preliminary adaptation and for other types of heat pumps.

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